CLIC*LHC Based FEL*Nucleus Collider

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Motivation

In principle, a FEL beam can be used for

the excitations of any fully ionised

relativistic nucleus beam to study

Nuclear Spectroscopy...

Motivation

- In such a FEL-Nucleus collider;

The accelerated fully ionized nuclei will “see” the keV energy photons as a MeV energy laser beam.

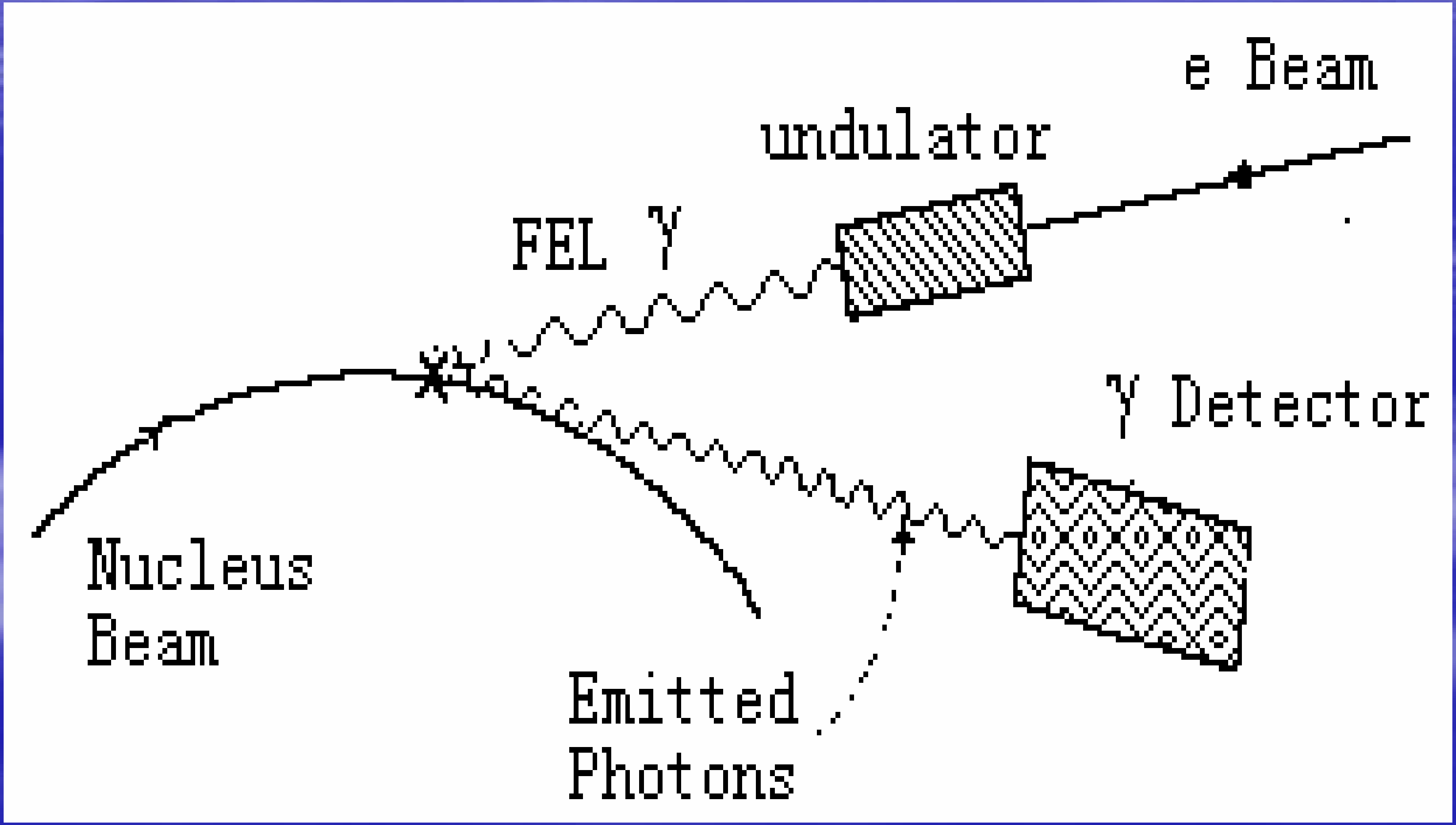
O. Yavas et al.
New tool for ‘old’ nuclear physics: FEL-Nucleus Colliders
Nuc. Instr. & Meth A428 (1999) 271-275

Motivation

- The main advantages compared to the traditional NRF methods are tunability, monochromaticity and high polarization of FEL beam.

- The advantages result in higher statistic and the possibility to investigate individual levels.

General schematic view of the proposed design



Relation of Excitation and FEL energies

The energy of FEL Photons needed for excitation at the corresponding nuclei level can be expressed as

$$\omega_{FEL} = \frac{E_{exc}}{2\gamma_N} = \frac{A}{Z}\frac{E_{exc}}{2\gamma_p}$$

$$\gamma_N = \frac{Z}{A}\gamma_p$$

for LHC : $\gamma_p = 7462$

- Due to good monochromaticity $\Delta E\gamma/E\gamma < 10^{-3} \div 10^{-4}$ with the typical obtainable number of photons (10^{13} γ/bunch) and excellent tunability, this method can be successfully used to investigate nuclear excitations with low multipolarity (E1 and M1) in wide energy region.
- Especially, collective excitations of nuclei can be analyze using the monochromaticity of FEL in detail.

CLIC*LHC Based FEL-Nucleus Collider

- FEL beam can be obtained from CLIC drive beam...
- Nucleus beams from LHC...
- CLIC*LHC Based FEL*Nucleus Collider !
- This collider allows to study Nuclear Spectroscopy precisely using tunable, monochromatic and coherent radiation FEL from CLIC which collide with LHC Nucleus beams (Pb, C, Sm, Au, Ce, Ba etc.)

The luminosity of the FEL-Nucleus collider :

$$L = \frac{n_\gamma n_{nuc}}{4\pi\sigma_x\sigma_y} f_c$$

The number of events :

$$R = L\sigma_{ave}$$

An ideal photon source used in (γ,γ') scattering experiments should have the following characteristics:

- High spectral intensity (I=N_γ /eV s)
- Good monochromaticity ($\Delta E_\gamma / E_\gamma$)
- Tunable in a broad energy range (IR - Hard X-ray)
- High degree of linear polarization (P_γ=100%)

Characteristics of the different photon sources

Photon Source	Spectral Intensity [γ/s·eV]	$\Delta E_\gamma/E_\gamma$ [%]	Pγ [%]	Target Mass M [g]
Compton Backscattered	0.15	2.7	100	70
Bremsstrahlung (Polarised)	20	Cont.	10-30	5
Bremsstrahlung (Unpolarised) + CB	1000	Cont.	10-20	5
Bremsstrahlung (Unpolarised)	1000	Cont.	0	1-2
Free Electron Laser	10^{17} MeV/E_{exc}	0.001	100	10^{-10}

Energy Ranges

- Energy range for E1 and M1 dipole excitations : $E_{exc} = 2\text{-}20$ MeV
- Energy of nucleus beam of LHC:

  $E_A = \gamma_A m_A c^2$, $\gamma_A = \gamma_p Z/A$, $\gamma_p \sim 7000$)
- Needed FEL energies:

  $\omega_{FEL} = 0.3 - 3$ keV (for LHC nucleus beams)

  (4-40 nm) $E_{exc} = 2\, \gamma_A \omega_{FEL}$
- Needed electron beam energy from CLIC

  $E_{electron} = 1.2 - 3.8$ GeV

Basic Requirements for SASE FEL Beam

- $\Delta E_e / E_e \sim \rho \sim 10^{-3}$ (ρ FEL Parameter)
- Transverse emittance $\varepsilon_x , \varepsilon_y \leq \lambda / 4\pi$

CLIC*LHC based FEL-nucleus collider

Advantages of CLIC FEL:

- Compact linac
- Existing equipment (if CLIC is built)

Disadvantages of CLIC FEL:

- High-frequency RF ⇒ large energy spread (short range wakes)
- Normal conducting ⇒ difficult to match time structure of nucleus beam

Possible solution:

⇒ Don't use CLIC main beam (energy too high after damping ring, emittance too large before, large energy spread …)

⇒ Use additional drive beam pulses to power a dedicated linac - 15 GHz could be used, in order to obtain a smaller energy spread

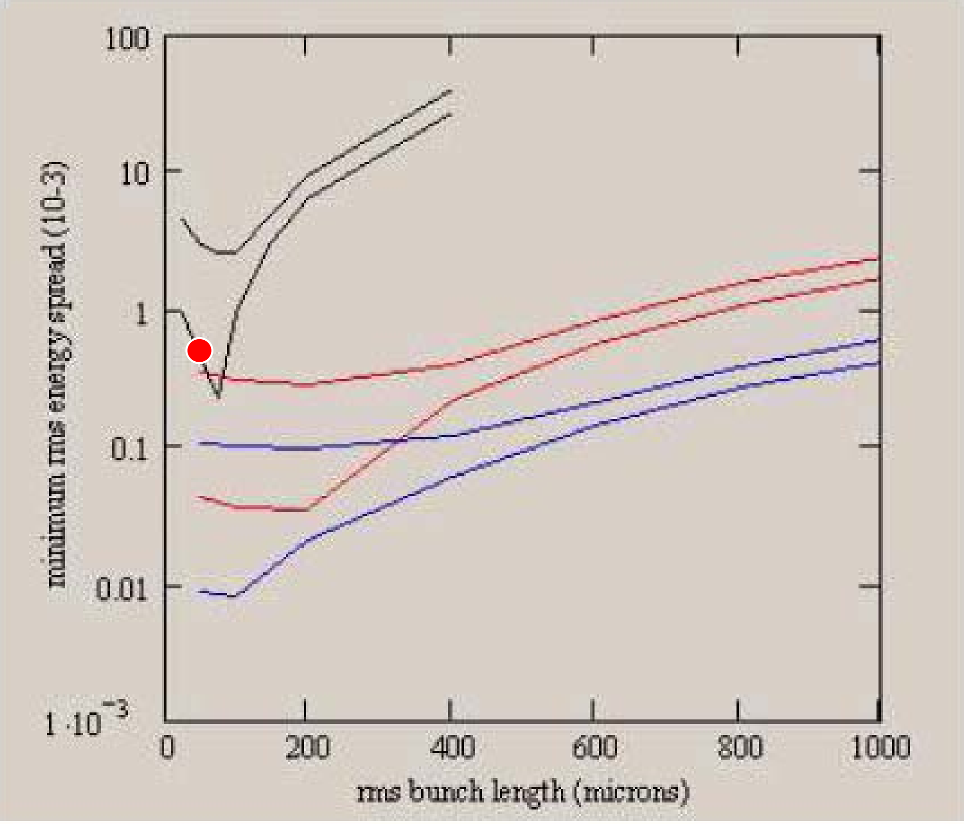


Figure 3: Minimum rms energy spread for 1.5 GHz (blue), 3 GHz (red), and 30 GHz (black) acceleration. The two lines for each colour correspond to a Gaussian (upper) and a uniform (lower) time profile of the bunch.

FEL & e- beam parameters

- Photon energy 0.3-3 keV ⇒ λ = 4 - 0.4 nm
- Electron beam energy E_b = 1 - 3.2 GeV
- Wiggler λ_W= 2.3 cm, B_W = 0.38 T, a_W = 0.8
- Q_b = 1 nC, $\Delta p/p \sim 10^{-3}$, $\varepsilon_{norm,rms} \sim 2\ 10^{-6}$, l_{bunch} = 50 μm
- Photon beam size (transverse) < 50 μm

Need dedicated source (photoinjector), staged bunch compressor
Assuming 15 GHz, 60 MV/m gradient & fill factor 0.5:

linac length < 70 m
wiggler length < 20 m

Time structure:

"minimum" scenario: single bunch, 100 Hz rep rate:

$$L := \frac{\left(n_\gamma \cdot n_{nuc}\right)}{4 \cdot \pi \cdot \sigma_x \cdot \sigma_y} \cdot n_b \cdot f_{rep}$$

$\sigma_x := 40 \cdot 10^{-6}$ $\quad n_\gamma := 4 \cdot 10^{13}$ $\quad f_{rep} := 100$

$\sigma_y := 40 \cdot 10^{-6}$ $\quad n_{nuc} := 0.94 \cdot 10^{8}$ $\quad n_b := 1$

$$L = 1.87 \times 10^{27}$$

We need more search on…

- Micro-structures of electron, FEL and nucleus beams…
- SASE FEL optimization…
- Luminosity, cross sections and event rates…
- Open problems of nuclear spectroscopy…
- Ion program of LHC…
- Detector Issues…

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Thank you for your invitation and collaboration

Ankara Group